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HOW AROUSAL AFFECTS YOUNGER AND OLDER ADULTS' MEMORY BINDING

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A number of recent studies have shown that associative memory for within-item features is enhanced for emotionally arousing items, whereas arousal-enhanced binding is not seen for associations between distinct items (for a review, see Mather, 2007, Perspectives on Psychological Science, 2, 33–52)*. The costs and benefits of arousal in memory binding have been examined for younger adults but not for older adults. The present experiment examined whether arousal would enhance younger and older adults' within-item and between-item memory binding. The results revealed that arousal improved younger adults' within-item memory binding but not that of older adults. Arousal worsened both groups' between-item memory binding.*

Memory binding is an essential component of episodic memory; it allows people to remember a combination of features of an object, a person, or an event. For example, if you witness a car accident, your ability to bind disparate elements of an event together will determine whether you remember which driver was in each car. How does having an emotionally arousing component as part of an event affect memory binding? Recent laboratory studies indicate that the emotional arousal elicited by a stimulus item (such as a picture or word) can either enhance or impair later memory for the features

or context associated with that item. For instance, a number of studies have found that memory for the color or location of emotional items is better than memory for the color or location of neutral items (Doerksen & Shimamura, 2001; Hadley & MacKay, 2006; Kensinger & Corkin, 2003; MacKay & Ahmetzanov, 2005; Mather, Gorlick, & Nesmith, 2009; Mather & Nesmith, 2008). However, other studies have found that memory for other items shown near emotionally arousing items or memory for which task was performed on emotionally arousing items is poorer than memory for these types of associated information for neutral items (Anderson & Shimamura, 2005; Cook, Hicks, & Marsh, 2007; Kensinger & Schacter, 2006).

The Effect of Arousal on Two Types of Memory Binding

To account for the discrepant effects of arousal on different aspects of memory binding, Mather (2007) proposed an object-based memory-binding framework. According to this framework, whether or not arousal enhances memory binding depends on whether the features to be bound are from the same target item (e.g., a car and its color) or from distinct items (e.g., a car and a pedestrian). When a target item is emotionally arousing, the arousal enhances the former type of binding (within-item memory binding) but does not improve the latter (between-item memory binding). This discrepancy is due to the way arousal influences attention allocation. Focused attention on an object is necessary to perceive its various features as a coherent whole (Treisman, 1998). When an arousing object attracts attention, it leads to enhanced memory binding of the features that are the focus of attention, which include all of the features that comprise the object itself. However, arousing objects may also reduce attention to the broader scope of the scene and interrelationships between the arousing object and other nearby objects, impairing between-item memory binding.

Aging and Memory Binding

The studies described above that revealed effects of arousal on memory binding were all conducted with younger adults. However, it remains unclear whether arousal has the same effects on memory binding in older adults. Previous studies examining the effects of emotional arousal on memory (but not memory binding) suggest that the effects remain similar in normal aging (Denburg, Buchanan, Tranel, & Adolphs, 2003; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002; Kensinger, Gutchess, & Schacter, 2007b). This

emotion-enhanced memory among older adults is consistent with findings that the amygdala, one of the emotional centers of the brain, shows relatively little decline in normal aging (for a review, see Mather, 2004). Despite an overall decline in memory performance with age, both younger and older adults show significantly higher activations in the amygdala for emotional stimuli than for neutral stimuli (e.g., Mather et al., 2004).

Unlike the relative similarities across age groups in the effects of arousal on memory, some recent studies have revealed age by valence interactions in memory, such that a smaller proportion of what older adults remember tends to consist of negative information than for younger adults (e.g., Charles, Mather, & Carstensen, 2003; Kensinger & Schacter, 2008; Mather & Knight, 2005; Thomas & Hasher, 2006; Tomaszczyk, Fernandes, & MacLeod, 2008). Of particular relevance for our hypothesized link between attention and the effects of arousal on memory binding, older adults tend to spend less time looking at negative stimuli and more time looking at positive stimuli than younger adults (e.g., Mather & Carstensen, 2003; Knight et al., 2007; Rosler et al., 2005; Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b). One possibility is that this might lead to less effective memory binding for negative than for positive stimuli among older adults. However, previous findings revealed that although the amount of time a younger adult looked at a neutral or emotional picture predicted their recognition accuracy for that picture, it did not predict their picture-location memory accuracy (Mather & Nesmith, 2008). Thus, what seems more critical than total study time for the arousal-enhanced location memory is the initial context encoding strength (e.g., Malmberg & Shiffrin, 2005). Given that both older and younger adults are most likely to look first at emotionally arousing pictures, regardless of their valence (Knight et al., 2007), it seems that the effects of arousal on picture-location binding should be similar across positive and negative stimuli for older adults. In this study, our main focus was to examine the effects of arousal on memory binding.

In contrast to the relative similarities across age groups in the effects of arousal on memory, there are clear differences in the overall effectiveness of memory binding. A number of studies using neutral items as stimuli have suggested that older adults compared with younger adults have deficits in within-item memory binding (Bayen, Phelps, & Spaniol, 2000; Chalfonte & Johnson, 1996; Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Naveh-Benjamin, 2000; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Guez, & Shulman, 2004; Kessels, Hobbel, & Postma, 2007). Mitchell,

Johnson, Raye, Mather, and D'Esposito (2000b) found that older adults' memory binding impairment was not the result of poor item or feature memory per se; rather, they have difficulty remembering item-feature combinations. To test this, they presented drawings of different objects in various locations on the computer screen. Each participant completed several blocks of trials. For each block, younger and older participants were instructed to either remember (1) only which objects were presented, (2) only in which location objects appeared, or (3) the combination of objects and their locations, and were only tested on the information that they were instructed to study. Compared with younger adults, older adults performed significantly worse on the combination task, whereas the two groups performed similarly on the first two single-feature tasks (see also Hartman & Warren, 2005).

Neuroimaging studies provide further evidence for older adults' binding deficit. The prefrontal cortex and the hippocampal-medial temporal region are critical for memory and memory binding (Achim & Lepage, 2005; Davachi & Wagner, 2002; Kramer et al., 2005; Eichenbaum & Bunsey, 1995; Kroll, Knight, Metcalfe, Wolf, & Tulving, 1996; Mather, 2007; Olson, Page, Moore, Chatterjee, & Verfaellie, 2006; Ryan & Cohen, 2004). These regions decline in volume in normal aging (Bartzokis, Beckson, Lu, Nuechterlein, Edwards, & Mintz, 2001; Raz et al., 2005) and show less memory-related activity in the hippocampus during memory encoding and retrieval tasks among older adults than among younger adults (Daselaar, Fleck, Dobbins, Madden, & Cabeza, 2006; Grady et al., 1995). More direct evidence of binding deficits comes from studies showing reduced hippocampal activity in older adults compared with younger adults during stimuli presentation conditions that elicit or require memory binding (Chee et al., 2006; Goh et al., 2007; Mitchell, Johnson, Raye, & D'Esposito, 2000a). Likewise, whereas younger adults show more left lateral prefrontal cortex activation when given a memory test about the previous format and location of items than when given an old-new memory test for the items themselves, older adults do not show this increased prefrontal activity during the source judgment task (Mitchell, Raye, Johnson, & Greene, 2006).

Older adults also show deficits in between-item memory binding for neutral items (e.g., Kilb & Naveh-Benjamin, 2007; Provyn, Slivinski, & Howard, 2007). For example, Naveh-Benjamin (2000) conducted a series of experiments investigating age differences in memory for pairs of distinct items (word-nonword pairs) and found that older adults have deficits in remembering item-item associations even when they have relatively intact memory for individual items

themselves. Another study conducted by Naveh-Benjamin, Brav, and Levy (2007) also showed that older adults did not remember pairs of items as well as did their younger counterparts. However, it is important to note that this deficit was reduced when older adults were instructed to use effective strategies for making connections between two items. In the current experiment, we explored the possibility that strategy use improves memory binding.

In summary, evidence from both behavioral and neuroimaging studies has suggested that older adults have deficits in within- and between-item memory binding for neutral items. However, it is not clear whether age-related memory binding deficits would be reduced for emotionally arousing materials, and whether the effects might vary depending on the type of memory binding. Given the theoretical reasons to think that the effects of arousal vary for different types of memory binding (Mather, 2007) and the fact that both types of binding may occur simultaneously in real life, we used an encoding paradigm in which participants were given the opportunity to make both types of associations at the same time (picture-location and picture-nearby object binding). Thus, the current study examined age differences in whether arousing components of stimuli enhance (1) memory for items, (2) within-item memory binding, and (3) between-item memory binding, and (4) whether strategy use improves both types of memory binding.

METHODS

Participants

We recruited 24 undergraduates ($M_{age} = 20.17$, age range 18–29, 11 males, 13 females, $M_{education} = 13.56$) and 24 older adults over 65 years old from various retirement communities ($M_{age} = 77.08$, age range 65–89, 6 males, 17 females, $M_{education} = 14.75$). The younger participants received course credit for their undergraduate Psychology classes, and older participants received monetary compensation for their participation. The experiments were conducted using a laptop at either at participants' homes, senior centers, or in our laboratory.

Materials

We used 64 pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) and from outside sources,

and 32 abstract shapes as stimuli. The pictures consisted of matched pairs of neutral and arousing pictures that were similar in appearance, complexity, content and focus of interest (for examples, see Mather & Nesmith, 2008). Each participant only saw one version from each picture pair so that if, for example, a participant saw a neutral version from picture pair 1, he or she did not view the arousing version from that pair. Across participants, the two versions were both presented with the same shape (e.g., the neutral and arousing versions from picture pair 1 were both presented with shape 1); thus, each participant saw 32 picture-shape pairs. Of these pairs, 16 were neutral images, and 16 were arousing images (8 positive and 8 negative). The number of stimuli was relatively small in order to avoid potential floor effects in older adults' memory. We also attempted to avoid ceiling effects in younger adults by pretesting the number of stimuli. In a previous pilot study, presenting 16 picture-shape pairs to younger adults resulted in a ceiling effect in a location memory test, whereas using 32 picture-shape pairs did not. We used PsyScope to present the stimuli and record the participants' responses. The screen was divided into 3×3 grids, with grid squares that were 300 mm wide and 248 mm high. The outer eight areas were used to present the images. On each slide, one picture and one shape simultaneously appeared in two of the eight cells. One image (either a picture or a shape) was always located higher than the other. Each stimulus type appeared in each location equally frequently.

Procedure

Participants first filled out the informed consent, demographic information, and a brief emotion questionnaire consisting of 10 positive and 10 negative emotion words (Positive and Negative Affect Schedule; Watson, Clark, & Tellegen, 1988).

Each participant then completed both an association and a non-association encoding condition. In the association condition, participants were asked questions that required them to make associations between each picture-shape pair. In the non-association condition, the tasks did not require making associations between the images. Participants were not informed about the upcoming memory tests; they were instructed to simply observe stimuli and answer questions by pressing appropriate keys on the keyboard.

The two encoding conditions alternated in four blocks of trials (i.e., association, non-association, association, and non-association); the order of which condition came first was randomized. Each block had 16 trials; and participants saw all 32 picture-shape pairs in the

first two blocks, which were then repeated in the second two blocks (the assignment of pictures to encoding conditions remained the same in the second presentation). Which versions of the matched pictures were shown was counterbalanced across participants, as was which encoding task was assigned to each picture-shape pair.

In the association condition, the following question appeared in the center of the screen simultaneously with the presentation of a picture-shape pair: "Is the picture higher (H) or lower (L) than the shape?" The participants were instructed to indicate their answers by pressing one of the keys marked "H" or "L," at which point the next pair was presented. In the non-association condition, a picture-shape pair was presented for 5000 ms during which the participants passively viewed the images. Immediately after the two images disappeared, either a blue or red dot was randomly presented in one of the eight outer cells of the screen with the question "Is the dot blue or red?" in the center of the screen. The participants were asked to indicate their answers by pressing one of the keys labeled with a blue sticker or a red sticker.

Immediately after the encoding phase, participants completed three types of memory tests in the following order: (1) a free recall test, (2) a location memory test, and (3) a pair memory test. In the recall test, we asked them to describe as many pictures as they could remember in as much detail as possible. The location memory test assessed within-item memory binding, or how well participants remembered combinations of pictures and their direct features (location). We presented each of the 32 pictures in two different locations, each of which had a number label. Participants were asked to indicate in which location they believed the picture had appeared in during the encoding trials by pressing one of the keys marked 1 through 8. The pair memory test assessed between-item memory binding, or how well participants remembered picture-shape combinations. We used a recognition test for the picture-shape combinations instead of a forced-choice procedure, as we wanted to keep the locations of picture-shape pairs constant both at encoding and at test (whether shapes were correctly paired with pictures or not at test) in order to avoid allowing participants to use location of shapes as a determinant of pair memory accuracy. To do so, we could not have included two pairs on the screen simultaneously with both in their original locations. On each test trial, participants saw a picture-shape pair and indicated whether each pair was a previously seen pair (there were 16 of these old pairs) or two previously seen items that had not been paired with each other (there were another 16 of these foils) by pressing either the blue (paired) or the red keys (not paired).

Participants provided arousal ratings for the pictures using 9-point scales (arousal: $1 =$ least arousing to $9 =$ most arousing). Three younger adults did not complete the ratings due to time constraints. We categorized positive and negative pictures according to IAPS' evaluation into an arousing group and their matched pictures into a neutral group. A 2 (group) $\times$ 2 (arousal: arousing and neutral) analysis of variance (ANOVA) revealed that there was a main effect of arousal, $F(1, 42) = 374.13$, $MSE = .53$, $p < .001$, $\eta_p^2 = .90$. However, there was an interaction between group and arousal ($M_{\text{young\_arousing}} = 6.51$, $SE = .26$; $M_{\text{young\_neutral}} = 3.02$, $SE = .23$; $M_{\text{old\_arousing}} = 6.47$, $SE = .25$; $M_{\text{old\_neutral}} = 3.92$, $SE = .22$), $F(1, 42) = 9.08$, $MSE = .53$, $p < .01$, $\eta_p^2 = .18$, suggesting that older adults rated neutral pictures as more arousing than did younger adults. We took this group difference into account in our analyses and will discuss the findings in the results section.

Participants also gave valence ratings using a 9-point scale (valence: $1 =$ most negative, $5 =$ neutral, $9 =$ most positive). We excluded three older adults' valence ratings from our analyses, as they reported after the experiment that they used the valence rating scales incorrectly. We also excluded all older subjects' ratings for one of the pictures in the negative category, which was a picture of a piece of pumpkin pie with a cockroach, as most older participants reported that they failed to see the cockroach due to its small size, resulting in rating the picture as positive rather than negative (older adult valence rating $M = 6.7$). A 2 (group) $\times$ 3 (valence: neutral, positive, negative) ANOVA revealed that there was a main effect of valence, $F(1, 39) = 449.85$, $MSE = .50$, $p < .001$, $\eta_p^2 = .92$. As expected, positive pictures received the highest valence ratings ($M = 6.36 \pm .23$) followed by neutral images ($M = 5.37 \pm .09$) and negative images ($M = 2.08 \pm .12$). There were no other significant effects.

At the end of the study, we administered the Consortium to Establish a Registry of Alzheimer's Disease (CERAD) word list memory test (Welsh et al., 1994) in order to exclude possible cases of dementia from our participant group. For this test, participants learned a list of 10 words and were later asked to recall and recognize them. In the standard CERAD test, recall and recognition tests are given across three time periods. In the current study, we administered the tests once immediately after the learning phase due to the time constraints; thus, the average scores would have been slightly lower if we had used the standard procedures. The proportion of words recalled was computed, and corrected recognition scores for words were calculated (hits – false-alarm rates). We excluded one older participant who scored 0.1 (3.79 *SD* below the older adult mean) on the recognition

test from further analyses. This participant would have scored even lower on the standard CERAD test, which is more difficult than the modified version used in our study. The proportion of recall and recognition for the remaining participants was as follows ($M_{\text{young\_recall}} = .60$, range $= .30–.80$; $M_{\text{older\_recall}} = .45$, range $= .20–.80$; $M_{\text{young\_recognition}} = .92$, range $= .79–1.00$; $M_{\text{older\_recognition}} = .88$, range $= .60–1.00$).

RESULTS

We report η_{p}^2 as a measure of effect size. As in the previous ratings analyses, the negative picture of a pie with a roach, which was rated as positive by most older participants, was excluded from all the analyses.

Current Emotions

An independent samples t test indicated that there was a significant difference between younger and older adults in reported positive affect ($M_{\text{young}} = 28.13 \pm 5.20$; $M_{\text{old}} = 33.39 \pm 8.64$), $t(47) = -2.54$, $p < .05$. Furthermore, we found a significant difference between the two groups in reported negative affect ($M_{\text{young}} = 14.92 \pm 5.34$; $M_{\text{old}} = 11.35 \pm 3.21$), $t(47) = 2.76$, $p < .01$. Older adults reported more intense positive emotions and less intense negative emotions than did younger adults. In the following analyses, the positive and negative affect scores from the emotion questionnaire (Watson et al., 1988) were included as covariates. However, we did not find a significant effect of the emotion questionnaire scores in any of the analyses and including them as covariates did not affect the significant findings; hence, we will not discuss it further.

Item Memory

During free recall, the experimenter noted descriptions of pictures provided by participants. Two coders later evaluated the accuracy of the descriptions, coding participants' descriptions with numbers that corresponded with each of the pictures. The inter-rater reliability was .87; the coders discussed discrepancies until mutual agreement was reached. One point was given for each accurately described picture, and the proportion of pictures recalled for each participant was computed.

A 2 (group: younger and older) $\times$ 2 (arousal type: arousing and neutral) $\times$ 2 (association condition: association and non-association) repeated-measure ANOVA revealed that younger adults recalled a

significantly larger proportion of the pictures than older adults did ($M_{young} = .26$, $SE = .02$; $M_{old} = .14$, $SE = .02$), $F(1, 45) = 11.85$, $MSE = .05$, $p < .05$, $\eta_p^2 = .21$ (see Table 1 for all means and standard errors). Arousing pictures were more likely to be recalled ($M_{arousing} = .29$, $SE = .02$; $M_{neutral} = .11$, $SE = .02$), $F(1, 45) = 79.79$, $MSE = .02$, $p < .001$, $\eta_p^2 = .64$. Moreover, there was an interaction between group and arousal ($M_{young\_arousing} = .37$, $SE = .03$; $M_{young\_neutral} = .14$, $SE = .02$; $M_{old\_arousing} = .21$, $SE = .03$; $M_{old\_neutral} = .07$, $SE = .02$), $F(1, 45) = 5.55$, $MSE = .02$, $p < .05$, $\eta_p^2 = .11$. The results indicated that, overall, participants had better recall for arousing than neutral pictures; however, the arousal-based memory enhancement was larger in younger adults. There was no main effect of association condition and no interaction between group and association condition. We found no interaction between association condition and arousal type.

As reported in the methods section, we found a significant group difference in arousal rating for the neutral pictures, suggesting that

Table 1. Proportion of items recalled and location and pair memory accuracy for arousing (positive and negative) versus neutral items in association versus non-association conditions

		Younger	Older
Recall			
Arousing-positive	Association	.41 (.07)	.29 (.07)
	Non-association	.24 (.04)	.15 (.04)
Arousing-negative	Association	.45 (.05)	.17 (.05)
	Non-association	.39 (.06)	.22 (.07)
Neutral	Association	.17 (.03)	.06 (.03)
	Non-association	.11 (.03)	.09 (.03)
Location memory			
Arousing-positive	Association	.84 (.05)	.70 (.05)
	Non-association	.80 (.05)	.70 (.05)
Arousing-negative	Association	.72 (.05)	.70 (.05)
	Non-association	.83 (.05)	.67 (.06)
Neutral	Association	.72 (.05)	.69 (.05)
	Non-association	.76 (.04)	.71 (.04)
Pair memory			
Arousing-positive	Association	.08 (.11)	−.02 (.11)
	Non-association	.10 (.07)	−.11 (.08)
Arousing-negative	Association	.10 (.09)	.07 (.10)
	Non-association	.21 (.10)	−.09 (.10)
Neutral	Association	.37 (.07)	.26 (.07)
	Non-association	.17 (.07)	.07 (.07)

Note. Standard errors are in parentheses.

older adults rated neutral pictures as more arousing than did younger adults. To examine the effect of this difference on item memory, we regrouped the pictures into arousing and neutral categories based on age group ratings. Using the average arousal rating scores by each group ($M_{young} = 4.73$, $M_{old} = 5.11$), we categorized pictures rated higher than the group average into an arousing group and pictures rated lower than the group average into a neutral group. This resulted in 33 arousing and 31 neutral pictures for the younger group, and 35 arousal and 29 neutral pictures for the older group. We conducted a 2 (group) $\times$ 2 (arousal type: arousing and neutral) repeated-measure ANOVA. There was a main effect of group ($M_{young} = .13$, $SE = .01$; $M_{old} = .06$, $SE = .01$), $F(1, 45) = 15.00$, $MSE = .006$, $p < .001$, $\eta_p^2 = .25$. There was also a main effect of arousal ($M_{arousing} = .15$, $SE = .01$; $M_{neutral} = .05$, $SE = .01$), $F(1, 45) = 95.80$, $MSE = .002$, $p < .001$, $\eta_p^2 = .68$. We found an interaction between group and arousal ($M_{young\_arousing} = .19$, $SE = .02$; $M_{young\_neutral} = .07$, $SE = .01$; $M_{old\_arousing} = .10$, $SE = .02$; $M_{old\_neutral} = .03$, $SE = .01$), $F(1, 45) = 4.41$, $MSE = .002$, $p < .05$, $\eta_p^2 = .09$. The results remained the same as those from the initial analyses using the arousal categorization according to the IAPS' evaluation. Participants had better recall for arousing than neutral pictures; however, the effect was larger for younger adults.

We examined differences in item memory for positively versus negatively arousing pictures. There was no main effect of valence but was an interaction between group and valence ($M_{young\_positive} = .32$, $SE = .04$; $M_{young\_negative} = .42$, $SE = .04$; $M_{old\_positive} = .22$, $SE = .04$; $M_{old\_negative} = .20$, $SE = .04$), $F(1, 45) = 4.69$, $MSE = .02$, $p < .05$, $\eta_p^2 = .09$. Younger adults had significantly better recall for negative than positive images, $F(1, 23) = 7.31$, $MSE = .01$, $p < .05$, $\eta_p^2 = .24$, whereas such a difference was not found for older adults (see Figure 1A). This pattern is consistent with previous findings of age by valence interactions in picture recall (e.g., Charles et al., 2003; Mather & Knight, 2005).

Location Memory (Within-Item Memory Binding)

We used a 2 (group) $\times$ 2 (arousal type) $\times$ 2 (association conditions) repeated-measures ANOVA to examine the proportion of the location forced-choice responses that were correct (see Table 1 for all means and standard errors). There was a marginal main effect of group; younger adults performed better than older adults ($M_{young} = 0.77$, $SE = 0.03$; $M_{old} = 0.68$, $SE = 0.03$), $F(1, 45) = 3.70$, $MSE = 0.09$, $p < .07$, $\eta_p^2 = .08$. There was no main effect of arousal
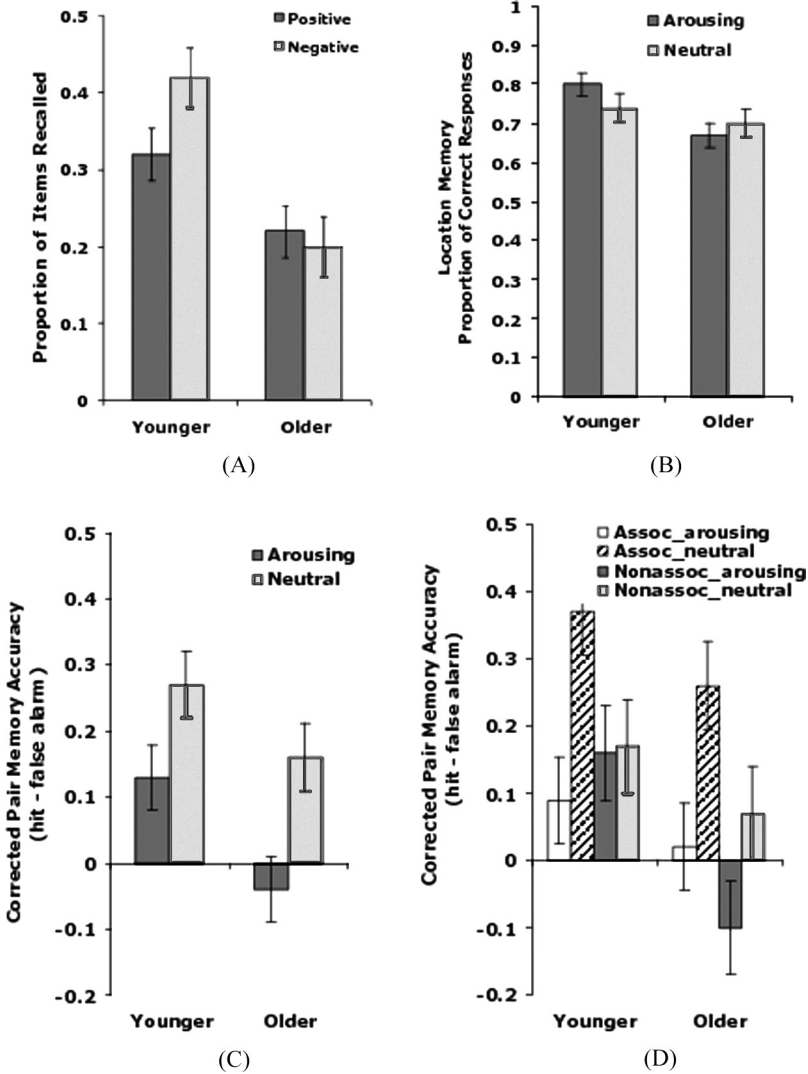
Figure 1. (A) Younger adults had better item memory for negative than positive photographs but older adults did not show this advantage for negative pictures. Arousing pictures **(B)** enhanced younger adults' location memory, but **(C)** impaired both groups' pair memory. **(D)** However, strategy use (association condition) enhanced memory for shape-photograph pairs that had neutral photographs. Error bars display the standard error.

suggesting that overall, there was no difference between location memory accuracy for arousing and neutral pictures. However, there was an interaction between group and arousal ($M_{young\_arousing} = .80$, $SE = .03$; $M_{young\_neutral} = .74$, $SE = .04$; $M_{old\_arousing} = .67$, $SE = .03$; $M_{old\_neutral} = .70$, $SE = .04$), $F(1, 45) = 4.65$, $MSE = 0.02$, $p < .05$, $\eta_p^2 = .09$ (see Figure 1B). Younger adults had better location memory for the arousing than neutral stimuli, $F(1, 23) = 6.18$, $MSE = 0.01$, $p < .05$, $\eta_p^2 = .21$, replicating previous findings (Mather & Nesmith, 2008), whereas older adults did not perform significantly differently in the two conditions. There was no main effect of association condition and no interaction between group and association condition. We found no interaction between association condition and arousal type.

To address potential effects of group differences in arousal rating on location memory, we conducted the following analyses using participants' arousal ratings described in the result section of item memory. A 2 (group) × 2 (arousal type: arousing and neutral) repeated-measure ANOVA found no significant effects. However, the same analysis performed only for the younger group revealed that there was a main effect of arousal, $F(1, 23) = 4.58$, $MSE = 0.01$, $p < .05$, $\eta_p^2 = .17$, indicating that younger adults had better location memory for arousing than neutral pictures. In contrast, there was no main effect of arousal for the older group. Arousal enhanced younger adults' but not older adults' location memory, as suggested in the initial analyses.

A 2 (group) × 2 (valence: positively vs. negatively arousing) repeated-measure ANOVA revealed that there was no main effect of valence and no interaction between group and valence ($M_{young\_positive} = .82$, $SE = .04$; $M_{young\_negative} = .78$, $SE = .04$; $M_{old\_positive} = .70$, $SE = .04$; $M_{old\_negative} = .63$, $SE = .04$).

Pair Memory (Between-Item Memory Binding)

Corrected pair-memory scores were calculated (hits – false-alarm rates). A 2 (group) × 2 (arousal type) × 2 (association condition) repeated-measures ANOVA revealed a main effect of group indicating that the younger adults performed significantly better than the older adults ($M_{young} = 0.20$, $SE = 0.04$; $M_{old} = 0.06$, $SE = 0.04$), $F(1, 45) = 6.93$, $MSE = 0.12$, $p < .05$, $\eta_p^2 = .13$ (see Table 1 for all means and standard errors). There also was a main effect of arousal, which indicated that, overall, participants had better memory for shape-picture pairs that involved neutral pictures than for those involving arousing pictures ($M_{neutral} = 0.21$, $SE = 0.04$; $M_{arousing} = 0.04$, $SE = 0.04$), $F(1, 45) = 11.22$, $MSE = 0.12$, $p < .01$, $\eta_p^2 = .20$ (see

Figure 1C). There was no interaction between group and arousal. These results suggest that, unlike for picture-location binding, for both age groups, arousal impaired picture-shape binding.

The analyses using participants' arousal ratings showed similar findings. A 2 (group) $\times$ 2 (arousal type) repeated-measure ANOVA indicated that there was a main effect of arousal ($M_{arousing} = 0.06$, $SE = 0.03$; $M_{neutral} = 0.23$, $SE = 0.04$), $F(1, 45) = 17.68$, $MSE = 0.04$, $p < .01$, $\eta_p^2 = .28$. There was a main effect of group ($M_{young} = 0.20$, $SE = 0.04$; $M_{old} = 0.09$, $SE = 0.04$), $F(1, 45) = 5.22$, $MSE = 0.06$, $p < .05$, $\eta_p^2 = .10$. As in the previous analyses using the predetermined arousal categories, we found no interaction between group and arousal, suggesting that arousal impaired picture-shape binding for both groups.

Being asked to make associations between the two stimuli improved pair memory ($M_{association} = 0.19$, $SE = 0.04$; $M_{non-association} = 0.07$, $SE = 0.03$), $F(1, 45) = 5.33$, $MSE = 0.11$, $p < .05$, $\eta_p^2 = .11$. We found no interaction between group and association condition, indicating that the effect was similar for younger and older adults. There was a marginal interaction between association condition and arousal type, $F(1, 45) = 3.50$, $MSE = .10$, $p < .07$, $\eta_p^2 = .07$.

A 2 (group) $\times$ 2 (association condition) repeated-measure ANOVA conducted only for neutral items indicated that making associations enhanced memory for shape-picture pairs that had neutral pictures ($M_{association} = 0.31$, $SE = 0.05$; $M_{non-association} = 0.12$, $SE = 0.05$), $F(1, 45) = 10.57$, $MSE = 0.09$, $p < .01$, $\eta_p^2 = .19$ (see Figure 1D). In contrast, a 2 (group) $\times$ 2 (association condition) repeated-measure ANOVA conducted solely for arousing items suggested that neither younger nor older adults benefited from making associations in terms of remembering pairs that had arousing pictures ($M_{association} = 0.06$, $SE = 0.05$; $M_{non-association} = 0.03$, $SE = 0.05$), $p > .69$.

A 2 (group) $\times$ 2 (valence: positively vs. negatively arousing) repeated-measure ANOVA revealed that there was no main effect of valence on pair memory and no interaction between group and valence.

DISCUSSION

As expected, younger adults showed significantly better item memory than did older adults, and both groups remembered arousing pictures better than neutral ones. Moreover, younger adults showed significantly better item memory for negative than positive stimuli, whereas older adults showed about the same level of item memory for both types of stimuli. This is consistent with previous findings that

attention and memory shift away from favoring negative stimuli and towards favoring positive stimuli as people age (for a review, see Mather & Carstensen, 2005).

The current results also replicated the previous finding that overall, older adults' location memory or within-item memory binding was poorer than that of younger adults (Chalfonte & Johnson, 1996; Mitchell et al., 2000b). Our main question was, however, to determine whether older adults, like younger adults, show arousal-enhanced location memory. The results indicated that location memory was enhanced by arousal in younger adults, as previously found (Mather & Nesmith, 2008); however, this arousal-enhanced location memory was not seen in older adults. The simplest explanation for this age difference may be that older adults have deficits in within-item memory binding regardless of whether stimuli are emotionally arousing or not, and that emotional components of items do not compensate for their binding deficits. Another possibility is that focused attention on arousing items enhanced only item memory but not within-item memory binding for older adults. Focused attention on emotional objects seems to occur in both younger and older adults; however, older adults' limited cognitive resources may only enable them to remember gist but not the details of arousing items whereas younger adults' greater cognitive resources may allow them to retain both item and feature information. In fact, our results showed that older adults performed slightly better at remembering the location of neutral than arousing items although they had better item memory for arousing than neutral images.

The failure of emotionally arousing items to lead to enhanced source memory for older adults is consistent with some findings by Kensinger, O'Brien, Swanberg, Garoff-Eaton, and Schacter (2007c). Their Experiment 1 results suggested that older adults had better item memory for positive and negative object names than that for neutral object names; however, this memory advantage did not extend to enhanced memory for the details associated with emotional objects (whether objects were seen or imagined), once their better recognition memory was taken into account. In contrast, younger adults showed an advantage for negative items in both item and source memory. However, these age differences in source memory are not always seen. For instance, in Kensinger et al.'s (2007c) Experiment 2, there was an age by valence interaction in item memory but not in source memory. Younger adults remembered negative but not positive items better than neutral items, whereas older adults remembered both negative and positive items better than neutral items. In contrast, both age groups had a source memory enhancement only for negative items. A similar dissociation between item and source memory, with

positive items showing enhanced item but not source memory only for older adults, was seen in a study by Kensinger, Garoff-Eaton, and Schacter (2007a). These findings suggest that older adults' focus on emotion regulation enhances item memory for positive stimuli, but does not enhance memory binding for the same stimuli. Likewise, in our study, we found age differences by valence in item memory, but not in associative memory.

It also remains possible that older adults' poor memory for item-feature combinations in our study was due to a failure to encode the feature (location) rather than a deficit in binding. A recent meta-analysis by Old and Naveh-Benjamin (2008) found an age-related deficit in various types of associative memory including within-item memory binding, such as memory for item-location combinations, memory for which word was spoken by which voice, and memory for which word appeared in which font. Although age effects were larger in some binding type categories than others, they found pronounced age differences in each binding type category, suggesting that memory for item-location conjunctions shows similar age effects as other types of within-feature binding. However, a question that needs further research is whether location-item binding is affected differently by emotional arousal than other types of within-item memory bindings (e.g., color-item conjunctions).

Consistent with our hypotheses and previous findings with younger adults, emotional components of target items did not enhance between-item memory binding in either group. The lack of arousal-based enhancement for between-item binding is predicted by Mather's (2007) object-based framework. Furthermore, our results suggested that arousal not only did not enhance associative memory but impaired it. Previous research, such as on the weapon focus effect, has shown that having an arousing item in a scene can impair memory for other aspects of the scene. Further research is needed to reveal whether the impaired between-item associative memory can be entirely accounted for by poorer item memory for information shown with arousing pictures or if there is some additional deficit specific to the link between the two items.

Across age groups, shape-picture pair memory was enhanced by making associations, but only when the pictures were neutral. The result was consistent with previous findings showing that making connections between two items enhanced older adults' pair memory (Naveh-Benjamin et al., 2007). However, our results further indicate that strategy use will not always be as effective when items contain affective components. This may be due to the fact that emotional components of items attract so much attention that strategy use does

not enhance memory for other irrelevant objects presented with the items. In our experiment, participants made perceptual associations between items; future studies should examine whether making other types of associations, such as semantic associations, would improve memory for arousing-neutral item pairs.

Lastly, potential methodological issues need to be considered. Although the number of stimuli was selected with the objective of maintaining above-chance performance in older adults and avoiding a ceiling effect in younger adults, it remains possible that the present results were partially due to the limited number of stimuli. It appears that we were able to avoid creating a ceiling effect in younger adults in all memory tests, but there may be a possible floor effect in older adults in the pair memory test. Another potential issue was that we could not randomize the order of memory tests, as the nature of the tests required the tests to be conducted in a particular order (i.e., we had to give the location test before the pair memory test, as the pair memory test would reveal the answer to the location test). It is possible that giving the pair memory test last contributed to the result that arousal did not enhance between-item memory binding. Future studies can also be improved by using the same test procedures for within-item and between-item memory binding in order to directly compare the performance of the two types of memory binding.

To conclude, the overall findings in the current study were consistent with the object-based framework, which suggests that arousal-enhancement occurs for within-object memory binding but not for between-object memory binding (Mather, 2007). Age differences, however, were seen in the effect of arousal on within-item memory binding—arousal did not enhance older adults' within-object memory binding. The parsimonious explanation may be that older adults have binding deficits regardless of types of stimuli. However, before drawing this conclusion, alternative explanations need to be ruled out, such as the possibility that feature or location memory impairments account for older adults' apparent within-item memory binding deficits. Future studies should also examine both types of memory binding in various contents and contexts in order to determine the costs and benefits of the strengths of binding in diverse situations.

REFERENCES

Achim, A. M., & Lepage, M. (2005). Neural correlates of memory for items and for associations: An event-related functional magnetic resonance imaging study. *Journal of Cognitive Neuroscience, 17,* 652–667.

Anderson, L., & Shimamura, A. P. (2005). Influences of emotion on context memory while viewing film clips. *American Journal of Psychology, 118,* 323–337.

Bayen, U. J., Phelps, M. P., & Spaniol, J. (2000). Age-related differences in the use of contextual information in recognition memory: A global matching approach. *Journals of Gerontology: Series B: Psychological Sciences and Social Sciences, 55B,* 131–141.

Bartzokis, G., Beckson, M., Lu, P. H., Nuechterlein, K. H., Edwards, N., & Mintz, J. (2001). Age-related changes in frontal and temporal volume in men: A magnetic resonance imaging study. *Arch Gen Psychiatry, 58,* 461–465.

Chalfonte, B. L., & Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Memory & Cognition, 24,* 403–416.

Charles, S. T., Mather, M., & Carstensen, L. L. (2003). Aging and emotional memory: The forgettable nature of negative images for older adults. *Journal of Experimental Psychology, 132,* 310–324.

Chee, M. W. L., Goh, J. O. S., Venkatraman, V., Tan, J. C., Gutchess, A., Sutton, B., Hebrank, A., Leshikar, E., & Park, D. (2006). Age-related changes in object processing and contextual binding revealed using fMR adaptation. *Journal of Cognitive Neuroscience, 18,* 495–507.

Cook, G., Hicks, J. L., & Marsh, R. L. (2007). Source monitoring is not always enhanced for valenced material. *Memory & Cognition, 35,* 222–230.

Cowan, N., Naveh-Benjamin, M., Kilb, A., & Saults, J. S. (2006). Life-span development of visual working memory: When is feature binding difficult? *Developmental Psychology, 42,* 1089–1102.

Daselaar, S. M., Fleck, M. S., Dobbins, I. G., Madden, D. J., & Cabeza, R. (2006). Effects of healthy aging on hippocampal and rhinal memory functions: An event-related fMRI study. *Cerebral Cortex, 16,* 1771–1782.

Davachi, L., & Wagner, A. D. (2002). Hippocampal contributions to episodic encoding: Insights from relational and item-based learning. *Journal of Neurophysiology, 88,* 982–990.

Denburg, N. L., Buchanan, T. W., Tranel, D., & Adolphs, R. (2003). Evidence for preserved emotional memory in normal older persons. *Emotion, 3,* 239–253.

Doerksen, S., & Shimamura, A. P. (2001). Source memory enhancement for emotional words. *Emotion, 1,* 5–11.

Eichenbaum, H., & Bunsey, M. (1995). On the binding of associations in memory: Clues from studies on the role of the hippocampal region in paired-associate learning. *Current Directions in Psychological Science, 4,* 19–23.

Goh, J. O., Chee, M. W., Tan, J. C., Venkatraman, V., Hebrank, A., Leshikar, E. D., Jenkins, L., Sutton, B. P., Gutchess, A. H., & Park, D. C. (2007). Age and culture modulate object processing and object-scene binding in the ventral visual area. *Cognitive Affective & Behavioral Neuroscience, 7,* 44–52.

Grady, C. L., McIntosh, A. R., Horwitz, B., Maisog, J. M., Ungerleider, L. G., Mentis, M. J., Pietrini, P., Schapiro, M. B., & Haxby, J. V. (1995, July 14). Age-related reductions in human recognition memory due to impaired encoding. *Science, 269,* 218–221.

Hadley, C. B., & Mackay, D. G. (2006). Does emotion help or hinder immediate memory? Arousal versus priority-binding mechanisms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 79–88.

Hartman, M., & Warren, L. H. (2005). Explaining age differences in temporal working memory. *Psychology and Aging. Special Issue: Emotion-Cognition Interactions and the Aging Mind, 20,* 645–656.

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., & Wilson, H. R. (2006a). Is there an age-related positivity effect in visual attention? A comparison of two methodologies. *Emotion, 6,* 511–516.

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., & Wilson, H. R. (2006b). Selective preference in visual fixation away from negative images in old age? An eye tracking study. *Psychology and Aging, 21,* 40–48.

Kensinger, E. A., Brierley, B., Medford, N., Growdon, J. H., & Corkin, S. (2002). Effects of normal aging and Alzheimer's disease on emotional memory. *Emotion, 2,* 118–134.

Kensinger, E., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? *Memory & Cognition, 31,* 1169–1180.

Kensinger, E. A., Garoff-Eaton, R. J., & Schacter, D. L. (2007a). Effects of emotion on memory specificity in young and older adults. *Journal of Gerontology: Psychological Sciences, 62,* 208–215.

Kensinger, E. A., Gutchess, A. H., & Schacter, D. L. (2007b). Effects of aging and encoding instructions on emotion-induced memory trade-offs. *Psychology and Aging, 22,* 781–795.

Kensinger, E. A., O'Brien, J. L., Swanberg, K., Garoff-Eaton, R. J., & Schacter, D. L. (2007c). The effects of emotional content on reality-monitoring performance in young and older adults. *Psychology And Aging, 22,* 752–764.

Kensinger, E. A., & Schacter, D. L. (2006). Amygdala activity is associated with the successful encoding of item, but not source, information for positive and negative stimuli. *Journal of Neuroscience, 26,* 2564–2570.

Kensinger, E. A., & Schacter, D. L. (2008). Neural processes supporting young and older adults' emotional memories. *Journal of Cognitive Neuroscience, 20,* 1161–1173.

Kessels, R. P. C., Hobbel, D., & Postma, A. (2007). Aging, context memory and binding: A comparison of "what, where and when" in young and older adults. *International Journal of Neuroscience, 117,* 795–810.

Kilb, A., & Naveh-Benjamin, M. (2007). Paying attention to binding: Further studies assessing the role of reduced attentional resources in the associative deficit of older adults. *Memory & Cognition, 35,* 1162–1174.

Knight, M., & Mather, M. (2006). The affective neuroscience of aging and its implications for cognition. In T. Canli (Ed.), *The biological bases of personality and individual differences* (pp. 159–183). New York: Guilford Press.

Knight, M., Seymour, T. L., Gaunt, J. T., Baker, C., Nesmith, K., & Mather, M. (2007). Aging and goal-directed emotional attention: Distraction reverses emotional biases. *Emotion, 7,* 705–714.

Kramer, J. H., Rosen, H. J., Du, A. T., Schuff, N., Hollnagel, C., Weiner, M. W., Miller, B. L., & Delis, D. C. (2005). Dissociations in hippocampal and frontal contributions to episodic memory performance. *Neuropsychology, 19,* 799–805.

Kroll, N. E. A., Knight, R. T., Metcalfe, J., Wolf, E. S., & Tulving, E. (1996). Cohesion failure as a source of memory illusions. *Journal of Memory and Language, 35,* 176–196.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *The international affective picture system (IAPS): Technical manual and affective ratings.* Gainesville, FL: University of Florida, The Center for Research in Psychophysiology.

MacKay, D. G., & Ahmetzanov, M. V. (2005). Emotion, memory, and attention in the taboo Stroop paradigm: An experimental analogue of flashbulb memories. *Psychological Science, 16,* 25–32.

Malmberg, K., & Shiffrin, R. M. (2005). The "one-shot" hypothesis for context storage. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 322–336.

Mather, M. (2004). Aging and emotional memory. In D. Reisberg & P. Hertel (Eds.), *Memory and emotion* (pp. 272–307). New York: Oxford University Press.

Mather, M. (2007). Emotional arousal and memory binding. *Perspectives on Psychological Science, 2,* 33–52.

Mather, M., Canli, T., English, T., Whitfield, S., Wais, P., Ochsner, K., Gabrieli, J. D. E., Carstensen, L. L. (2004). Amygdala responses to emotionally valenced stimuli in older and younger adults. *Psychological Science, 15,* 259–263.

Mather, M., & Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychological Science, 14,* 409–415.

Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Sciences, 9,* 496–502.

Mather, M., Gorlick, M. A., & Nesmith, K. (2009). The limits of arousal's memory impairing effects on nearby information. *American Journal of Psychology, 122,* 349–370.

Mather, M., & Knight, M. (2005). Goal-directed memory: The role of cognitive control in older adults' emotional memory. *Psychology and Aging, 20,* 554–570.

Mather, M., & Nesmith, K. (2008). Arousal-enhanced location memory for pictures. *Journal of Memory and Language, 58,* 449–464.

Mitchell, K. J., Johnson, M. K., Raye, C. L., & D'Esposito, M. (2000a). fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Cognitive Brain Research, 10,* 197–206.

Mitchell, K. J., Johnson, M. K., Raye, C. L., Mather, M., & D'Esposito, M. (2000b). Aging and reflective processes of working memory: Binding and test load deficits. *Psychology and Aging, 15,* 527–541.

Mitchell, K. J., Raye, C. L., Johnson, M. K., & Greene, E. J. (2006). An fMRI investigation of short-term source memory in young and older adults. *Neuroimage, 30,* 627–633.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Naveh-Benjamin, M., Brav, T. K., & Levy, O. (2007). The associative memory deficit of older adults: The role of strategy utilization. *Psychology and Aging, 22,* 202–208.

Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The associative memory deficit of older adults: Further support using face-name associations. *Psychology and Aging, 19,* 541–546.

Naveh-Benjamin, M., Guez, J., & Shulman, S. (2004). Older adults' associative deficit in episodic memory: Assessing the role of decline in attentional resources. *Psychonomic Bulletin & Review, 11,* 1067–1073.

Old, S. R., & Naveh-Benjamin, M. (2008). Differential effects of age on item and associative measures of memory: A meta-analysis. *Psychology and Aging, 23,* 104–118.

Olson, I. R., Page, K., Moore, K. S., Chatterjee, A., & Verfaellie, M. (2006). Working memory for conjunctions relies on the medial temporal lobe. *Journal of Neuroscience, 26,* 4596–4601.

Provyn, J. P., Sliwinski, M. J., & Howard, M. W. (2007). Effects of age on contextually mediated associations in paired associate learning. *Psychology and Aging, 22,* 846–857.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D, Williamson, A., Dahle, C., Gerstorf, D., & Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex, 15,* 1679–1689.

Rosler, A., Ulrich, C., Billino, J., Sterzer, P., Weidauer, S., Bernhardt, T., et al. (2005). Effects of arousing emotional scenes on the distribution of visuospatial attention: Changes with aging and early subcortical vascular dementia. *Journal of the Neurological Sciences, 229,* 109–116.

Ryan, J. D., & Cohen, N. J. (2004). Processing and short-term retention of relational information in amnesia. *Neuropsychologia, 42,* 497–511.

Thomas, R. C., & Hasher, L. (2006). The influence of emotional valence on age differences in early processing and memory. *Psychology and Aging, 21,* 821–825.

Tomaszczyk, J. C., Fernandes, M. A., & MacLeod, C. M. (2008). Personal relevance modulates the positivity bias in recall of emotional pictures in older adults. *Psychonomic Bulletin & Review, 15,* 191–196.

Treisman, A. (1998). Feature binding, attention and object perception. *Philosophical Transactions of the Royal Society of London Series B Biological Sciences, 353,* 1295–1306.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54,* 1063–1070.

Welsh, K. A., Butters, N., Mohs, R. C., Beekly, D., Edland, S., Fillenbaum, G., & Heyman, A. (1994). The Consortium to Establish a Registry for Alzheimer's Disease (CERAD). Part V. A normative study of the neuropsychological battery. *Neurology, 44,* 609–614.